External ballistics: flying bullet temperature change

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Abstract

This study presents the report on the temperature change of a flying bullet. The authors tried to describe and solve this challenge numerically and compare with an actual experiment. The research deals with the temperature change on the outside surface of a bullet after leaving a barrel. Additionally, the same problem was solved numerically using Abaqus Explicit code. Finally, the actual initial temperatures for the different diameters of bullets were measured. These results are implemented into the numerical solution as initial conditions to calculate the temperature change of travelling bullets. Furthermore, the actual temperature of flying bullets were measured at some distance from the rifle.

Keywords: bullet temperature, numerics, experiment

1. Introduction

A ballistic projectiles flying through the ambient are exposed to high temperature changes. There is a variety of techniques to measure a surface temperature changes including laser scanning up to thermal emission measurements. Noteworthy is that the flying bullet speed is about 2÷3 Mach. It gives a distant ca. 1m during 0.001s flight. This work presents the initial step, however, the final results is to determine a temperature change after bullet perforation of soft tissue. At this moment the primary objective is to catch a bullet temperature print during first moment of flight. Base on the actual, however, preliminary experiment it is possible to see the temperature on the front as well as rear part of bullet. A general view is presented in the Fig.1.

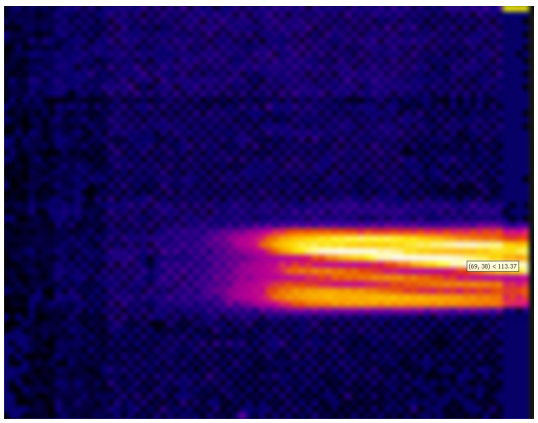

Figure 1: A temperature measured for 7.62 bullet at velocity $740\frac{m}{s}$ 2.5m from the barrel, average surface temperature is 113 Celsius

This result was obtained during a series of actual experiments base on the thermal measurement using high speed thermal camera. The presented frame rate was about 10000fps. Regarding the initial speed about $740\frac{m}{s}$ one picture shows the 0.074m trace of the bullet. Nevertheless, it is enough to catch the temperature change on both edges of the bullet. Moreover, authors measured different types of the bullets starting from 9mm pistol, .308 hunting up to 7.62mm armour-piercing bullet.

2. Numerical prediction

A proposed formula is governed by basic differential equation [2]. The acceleration in time of the bullet with the mass M is balanced by a drag force F. Equation (1) provides directly to determine drag force.

$$M\frac{\mathrm{d}u(x)}{\mathrm{d}t} + F = 0 \tag{1}$$

Moreover, the change of the distance of bullet x in time function t is equal to velocity $u(x)$, see Eqn (2).

$$\frac{\mathrm{d}x}{\mathrm{d}t} - u(x) = 0 \tag{2}$$

Temperature of a bullet can be obtained form an energy balance equation, see Eqn (3) moving M and λ to the right of Eqn (3). Where $\overline{h}$ means the average heat transfer.

$$M\lambda\frac{\mathrm{d}T}{\mathrm{d}t} = \overline{h}\pi D^2(T_n - T) \tag{3}$$

The presented derivatives in Eqn. (1-3) are relatively easy to solve base on forward with time integration. The velocity, displacement, and temperature of the bullet are obtained base on the following integrals:

$$u(x_{i+1}) = u(x_i) + \int_0^t \frac{\mathrm{d}u(x_i)}{\mathrm{d}t}\mathrm{d}t \tag{4}$$

$$x_{i+1} = \int_0^t \frac{\mathrm{d}x_i}{\mathrm{d}t}\mathrm{d}t \tag{5}$$

$$\Theta_{i+1} = \Theta_i + \int_0^t \frac{\mathrm{d}\Theta_i}{\mathrm{d}t}\mathrm{d}t \tag{6}$$

The solution of the above equation is obtained using a classic Euler integration scheme Eqn (7). Here, the direction φ is presented by first derivative of function y.

$$y_{i+1} = y_i + \varphi \cdot h \tag{7}$$

Moreover, φ represents the location of the new point of solution and its often called a predictor Eqn (8). The solution for all above equations is obtained base on Scilab code [3]. The presented procedures were programmed by the authors.

$$\varphi = x_{i+1} - x_i \tag{8}$$

3. Results and conclusions

Base on the preliminary experimental tests, where the initial bullet temperatures were measured, the initial conditions were obtained i.e. initial temperature of a bullet. Considering all above equations the results of the velocity, displacement and temperature for exampled bullet of calibre 7.62 is presented in the Fig.(2).

The continuous line represents the distance that is done by a bullet in 1s. The black dots shows the temperature changes in time, starting from the 113 Celsius. This temperature was measured during an actual experiment described previously. A velocity is the last dotted line. The initial velocity, measure during the experiment, was $740\frac{m}{s}$.

Finally, as a future work a bullet temperature and velocity at the distance range 100, 200 and more must be measure to confirm and verify the properties used in these computations. This work is in undergoing part of the study. Nevertheless, a relatively small measurement area must be matched with the bullet trajectory.

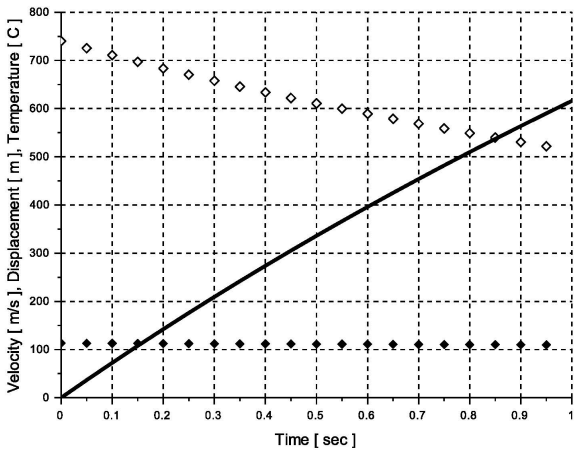

Figure 2: Velocity, displacement and temperature of flying 7.62 bullet in time

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